

RESPONSE OF LARVAL *CULEX PIPPIENS* (DIPTERA: CULICIDAE) TO LIGHT PRODUCED BY LIGHT EMITTING DIODES¹

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ABSTRACT: In tests with subaquatic light traps, light from green light emitting diodes (LED's) was more attractive to larval *Culex pipiens* than light from any other source tested. Light from amber LED's was as attractive as white (full visible spectrum) light from incandescent lamps typically used in subaquatic traps. All four larval instars were equally attracted to these light sources. Orange, red, infrared and unlit LED's were all much less attractive than white light and did not differ significantly from each other. Light emitting diodes offer significant advantages over incandescent lamps as attractors for subaquatic traps.

Knowledge of relative species abundance, or presence of a particular species, is important in mosquito surveillance and control operations. Aerial light traps are widely used as mosquito surveillance tools because adult mosquitoes of many species are attracted to light. Less well known is the fact that larvae of various mosquito species also are attracted to light. Since Hungerford *et al.* (1955) first reported mosquito larvae among the arthropod fauna entering submerged aquatic (subaquatic) light traps, there have been additional reports of culicid larvae entering such traps (Husbands, 1967; Ervin and Haines, 1972; Brown, 1976).

Subaquatic light traps used specifically to sample populations of mosquito larvae have been tested by Washino and Hokama (1968), Bertram *et al.* (1983) and Weber (1985). In several instances, subaquatic traps collected larvae of various *Aedes*, *Anopheles* or *Culex* species in larger numbers than other capture methods indicated were present (Husbands, 1967; Washino and Hokama, 1968; Weber, 1985). Traps used in those three studies had, as attractants, incandescent lamps which emitted white light.

Other light sources and colors of light have been tested for attractiveness to mosquito larvae. These include various colors of Betalights, glass tubes containing tritium and a phosphor (Bertram *et al.*, 1970; Service *et al.*, 1983) and "chemical light" in the form of Cyalume lightsticks³ (Service *et al.*, 1983).

The possibility of using solid state light sources as attractors in suba-

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quatic traps has not been examined. This paper reports the relative attractiveness to *Culex pipiens* L. larvae of light produced by commercially available colors of light emitting diodes (LED's) and responses of the four instars to these colors.

MATERIALS AND METHODS

Tests were conducted on 13 nights during the summers of 1985 and 1986. Testing was done outdoors in pools made by lining 1 m² by 19 cm deep wooden frames with 0.15 mm (6 mil) thick, black plastic sheet. These were filled to 15 cm with 151 liters of tapwater which had been aged 24-48 hours. After each test, pools were drained and allowed to dry out thoroughly so no larvae were carried over to later tests.

Larvae for tests were taken from populations in outdoor artificial breeding sites maintained for *Culex* studies (Weber and Weber, 1985). Two hundred *C. pipiens* larvae were used in each test, 50 of each instar. These were counted out late in the afternoon prior to a test and kept in beakers, segregated by instar, until 20:00 Eastern Daylight Time, when they were placed in test pools. Larvae were released into the center of a pool and allowed to disperse for 30 minutes before trap lights were turned on. Trap contents were collected at 08:00 the following morning, before trap lights were turned off. Formaldehyde was added to each sample to kill and preserve larvae until counting and instar determination.

Table 1 presents color and technical data for the light sources used. The white (full visible spectrum) light source was a clear, tungsten filament incandescent lamp of the "grain of wheat" type. The green, red, orange and amber light sources were commercially obtained LED's. The infrared (IR) light source was an IR emitting diode (IRED). The unlit trap contained an LED which was not turned on during tests. Traps with unlit and white lamps served as controls. The unlit one was used to determine whether the physical trap alone was attractive. The white lamp was used because it had been tested in previous subaquatic trapping experiments and was known to be attractive to mosquito larvae (Weber, 1985). An IR source was included in these tests because IR wavelengths have not previously been tested for attractancy to mosquito larvae but have been reported to be attractive to *Aedes aegypti* (L.) adults (Mangum and Callahan, 1968).

Figure 1 shows the arrangement of traps and colors during tests. Subaquatic traps containing the light sources to be tested were similar to those described by Weber (1985), but somewhat smaller, and were equipped with translucent, funnel-shaped gates. They were equidistantly spaced, 41.9 cm apart, around a 94 cm diameter floating plastic ring, held

centered in the pool by wires. Trap openings faced toward the pool's center and were centered 32 mm below the water surface with the long axis of traps parallel to the surface. The order of colors around the ring was kept constant for all tests. Clockwise, this order was white, unlit, green, red, orange, amber and IR.

To minimize possible interactions between trap colors and moonlight, or skylight, two replications of the test setup were made on each night of testing. In one, the ring was oriented so the trap with the white light

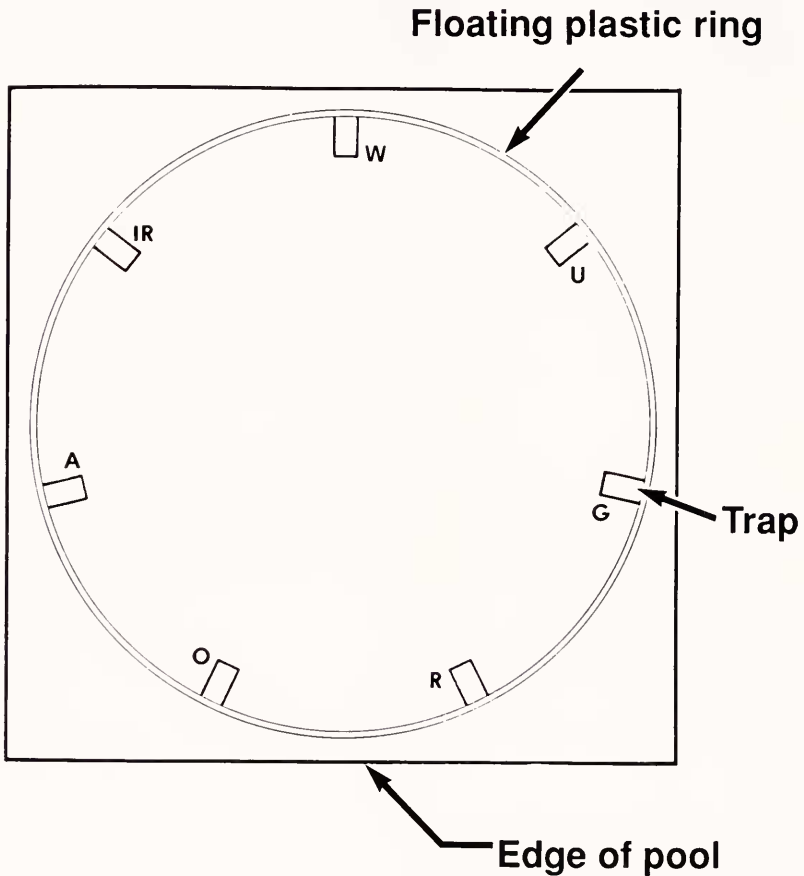


Figure 1. Arrangement of traps and colors during tests (top view). Colors tested were W (white), U (unlit), G (green), R (red), O (orange), A (amber) and IR (infrared).

source was North; in the other, South. Moonlight is believed to compete with trap lights and has been found to decrease aerial light trap catches of adult mosquitoes (Pratt, 1948; Provost, 1959; Barr *et al.*, 1963; Bidingmayer, 1967) and adults of other insect taxa (Williams, 1936; Williams and Singh, 1951; Bowden and Church, 1973). Skylight, a downward reflection from clouds, was considered important during these tests because of light from a metropolitan area 1 km north of the research site.

Catches of adult mosquitoes in aerial light traps are directly related to power output (brightness) of incandescent lamps used as attractors (Pratt, 1944; Barr *et al.*, 1960; Barr *et al.*, 1963). No data suggest that larval mosquitoes might differ from adults in this response, or that LED attraction might not vary with brightness. For these reasons power outputs of all light sources were adjusted to similar levels (Mims, 1973; GTE Products Corporation, 1984). For LED's this was achieved by incorporating a 1/2 watt, 5% fixed resistor into each circuit, which limited LED and IRED currents to 21.4 milliamperes (mA) $\pm$ 0.8 mA. Voltage applied to the tungsten lamp was adjusted so that filament current was 20.9 mA. All light sources had the same physical size, 8 mm long x 4.5 mm diameter. Power for all sources was supplied by 6-volt rechargeable batteries.

Data were analyzed using SAS Institute's General Linear Models Procedure (PROC GLM, SAS User's Guide, pp 433-506) (SAS Institute, 1985). Because the fraction of the instar population attracted to a particular color was from a fixed number of larvae (50), it was appropriate to use the arcsine-square root transformation. Data were then analyzed as a split-split plot design (Gomez and Gomez, 1984) where nightly trials were the blocks (replications), trap orientation the main plot factor, response by instar the split plot factor. For each factor, means were compared using the LSD procedures (SAS User's Guide, p 471) (SAS Institute, 1985). Significance reported below was determined at the 5% level.

RESULTS AND DISCUSSION

Nightly catches of larvae varied significantly. Of the 200 larvae in each test, total number captured per night by the 7 traps in a pool ranged from 90 (45%) to 1 (0.5%), with the nightly average being 16.5 larvae (8.25%). Several factors could explain variability in nightly captures. One is that traps were operated from 20:30 to 08:00 regardless of daylength. Over the period of testing this resulted in varying amounts of actual darkness during the operating period, with corresponding variability in nightly trapping time. Other factors possibly contributing to nightly variation relate to the phase of the moon and the amount of nightly cloud cover, thus to varying competition with sky or moonlight.

Orientation of traps with the white light North or South had no significant effect on catch, but larval response to colors was significant. This indicates that whatever the source of *nightly* catch variation, differential catches by the traps were not due to interaction between their light sources and light from the sky or moon.

Total catches of the four instars varied significantly; however, response by instar to the various colors did not. In decreasing numbers of larvae captured, the instars ranked 4th, 3rd, 2nd, 1st (184, 108, 85, 51 larvae respectively), but the difference between 3rd and 2nd instar catches was not significant. Because instar response was greatest for larger (4th instar) larvae and progressively less for each smaller instar, it seems reasonable to attribute differential response to differences in size of the larval instars. Simply put, smaller larvae had a greater distance to travel (relative to body size) from the release point to a trap than did larger larvae, although all instars were equally attracted to particular colors.

Colors varied significantly in attractiveness (Table 2). Green LED's were significantly more attractive than any other light source. Amber LED's and white incandescent lamps did not differ significantly in attractancy. All other colors, and unlit, were significantly less attractive than white lamps. Larval responses to orange, red, IR and unlit sources did not differ significantly. Comparison of total catches of the white and unlit sources (68 and 6 larvae, respectively) indicates that the trap itself was not attractive to larvae. Infrared and unlit sources caught less than any others (7 and 6 respectively), indicating larval *C. pipiens* are not attracted to IR at the wavelength and power output level used in these tests.

These results show that larval *C. pipiens* are attracted to light produced by green and amber LED's. Light from green LED's captured 3 times more larvae than did light from white incandescent lamps and amber LED's captured 1.4 times more than white incandescent sources, but that difference was not significant. All larval instars appear to be equally attracted to these sources. Additional, preliminary testing, has shown that pupal *C. pipiens* are also attracted to light from LED's of these colors. Experiments are underway to determine what other mosquito species are attracted, as larvae, to solid state light sources.

Solid state light sources are readily available and offer several advantages over incandescent lamps. These include low cost (20 to 40 cents), long life (about 1,000 h at maximum current ratings), energy efficiency (low voltage and current requirements), plus consistent color output over life of the device and resistance to rough handling because they do not produce light by means of a heated wire filament.

Table 1. Light source color and technical data.

Visual Color	Principal Wavelength ¹	Half Width ¹	Light Source Model Number	Supplier ²
Green	565 (nm)	30 (nm)	LN31GPHL ³	Digi-Key Corp.
Amber	590	30	LN41YPHL ³	Digi-Key Corp.
White	N.A.	N.A.	C22505	Chaney Electronics
Orange	630	40	LN81RPHL ³	Digi-Key Corp.
Red	700	100	LN21RPHL ³	Digi-Key Corp.
Infrared	880	N.A.	XC-880-A	Radio Shack

¹Taken from manufacturer's literature. N.A. = Not Available.

²Addresses: Digi-Key Corporation, 701 Brooks Ave. South, P.O. Box 677, Thief River Falls, Minnesota, 56701-0677. Chaney Electronics, Denver, Colorado, is no longer in business and this lamp is not available. Radio Shack carries a 1.5 volt incandescent lamp of the same size, style and amperage which could be substituted. Radio Shack has outlets located worldwide.

³The manufacturer's (Panasonic Industrial Company) optoelectronic device part number.

Table 2. Response of *Culex pipiens* larvae to Light Emitting Diode colors.

Visual Color	Total Capture ¹	%	Daily Range	Mean ²
Green	206	3.96	0-21 larvae	7.92 ^A
Amber	96	1.85	0-9 larvae	3.69 ^B
White	68	1.31	0-5 larvae	2.61 ^B
Orange	28	0.54	0-4 larvae	1.08 ^C
Red	18	0.35	0-4 larvae	0.69 ^C
Infrared	7	0.13	0-1 larvae	0.27 ^C
Unlit	6	0.12	0-4 larvae	0.23 ^C

¹Total larvae captured during the tests, regardless of instar.

²Average daily catch by all traps of that color. Means followed by the same letter are not significantly different from each other based on Fisher's Least Significant Difference Test ($\alpha = 0.05$).

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LITERATURE CITED

- Barr, A.R., T.A. Smith and M.M. Boreham. 1960. Light intensity and the attraction of mosquitoes to light traps. *J. Econ. Entomol.* 53:876-880.
- Barr, A.R., T.A. Smith, M.M. Boreham and K.E. White. 1963. Evaluation of some factors affecting the efficiency of light traps in collecting mosquitoes. *J. Econ. Entomol.* 56:123-127.
- Bertram, D.S., M.G.R. Varma, R.G. Page and O.H.U. Heathcote. 1970. A Betalight trap for mosquito larvae. *J. Med. Entomol.* 7:267-270.
- Bidlingmayer, W.L. 1967. A comparison of trapping methods for adult mosquitoes: Species response and environmental influence. *J. Med. Entomol.* 4:200-220.
- Bowden, J. and B.M. Church. 1973. The influence of moonlight on catches of insects in light-traps in Africa. Part II. The effect of moon phase on light-trap catches. *Bull. Entomol. Res.* 63:129-142.
- Brown, A.G. Jr. 1976. An inexpensive aquatic light trap for sampling mosquito larvae. *Calif. Vector Views* 23:4-6.
- Ervin, J.L. and T.A. Haines. 1972. Using light to collect and separate zooplankton. *Prog. Fish-Cult.* 34:171-174.
- Gomez, K.A. and A.A. Gomez. 1984. Statistical procedures for agricultural research. John Wiley and Sons, Inc., New York.
- GTE Products Corporation. 1984. Sylvania miniature lighting products handbook, Form 204. GTE Products Corporation, Hillsboro, New Hampshire.
- Hungerford, H.S., P.J. Spangler and N.A. Walker. 1955. Subaquatic light traps for insects and other animal organisms. *Trans. Ks. Acad. Sci.* 58:387-407.
- Husbands, R.C. 1967. A subsurface light trap for sampling aquatic insect populations. *Calif. Vector Views* 14:81-82.
- Mangum, C.L. and P.S. Callahan. 1968. Attraction of near-infrared radiation to *Aedes aegypti*. *J. Econ. Entomol.* 61:36-37.
- Mims, F.M. III. 1973. Light emitting diodes. The Bobbs-Merrill Co., Inc., New York.
- Pratt, H.D. 1944. Studies on the comparative attractiveness of 25, 50 and 100 watt bulbs for Puerto Rican *Anopheles*. *Mosq. News* 4:17-18.
- Pratt, H.D. 1948. Influence of the moon on light trap collections of *Anopheles albimanus* in Puerto Rico. *J. Natl. Malaria Soc.* 7:212-220.
- Provost, M.W. 1959. The influence of moonlight on light-trap catches of mosquitoes. *Ann. Entomol. Soc. Am.* 52:261-271.
- SAS Institute. 1985. SAS user's guide: Statistics, 5th ed. SAS Institute, Cary, N.C.
- Service, M.W., S. Sulaiman and R. Esena. 1983. A chemical aquatic light trap for mosquito larvae (Diptera: Culicidae). *J. Med. Entomol.* 20: 659-663.
- Washino, R.K. and Y. Hokama. 1968. Quantitative sampling of aquatic insects in a shallow-water habitat. *Ann. Entomol. Soc. Am.* 61:785-786.
- Weber, R.G. 1985. An aquatic light trap for possible use in mosquito larvae surveillance. *Proc. N.J. Mosq. Control Assoc.* 72:122-125.
- Weber, R.M. and R.G. Weber. 1985. The egg raft seam as an indicator of species in *Culex pipiens* and *Culex restuans*. *Mosq. System.* 17:363-370.
- Williams, C.B. 1936. The influence of moonlight on the activity of certain insects, particularly of the family Noctuidae, as indicated by a light trap. *Philos. Trans. R. Soc. (B)* 226:357-389.
- Williams, C.B. and B.P. Singh. 1951. Effect of moonlight on insect activity. *Nature (Lond.)* 167:853.